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Solar, Safety and Security Window Films: **Tech Bulletin**

Understanding Iridescence

What is iridescence?

Iridescence describes the shifting patterns that are observed on films under some lighting conditions, most notably when it is dark outdoors and the indoors is illuminated. "Pearlescence", an "oil slick" look, or shifting "fringes" along the surface of a film are the most common descriptions of iridescence. Because customers desire a uniform appearance of their windows at all times of day, the presence of iridescence has become a source of complaints in the window film industry. As energy conscious consumers switch to energy efficient lighting, complaints about iridescence may become more common so it is important to know what causes it, and how to minimize or eliminate it.

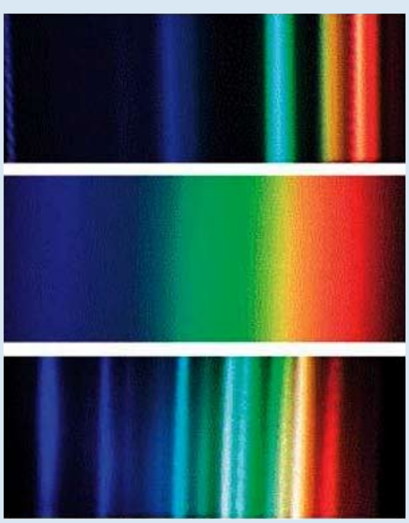
What causes iridescence?

Iridescence can occur whenever light strikes a "thin film". The phenomenon that causes this effect on window film also causes the rainbow effect on a thin film of oil in water, peacock feathers, and soap bubbles. It results from a phenomenon stemming from the wave nature of light known as "interference".

One or both of two things will contribute to iridescence. Firstly, if a film has small variations in thickness across a surface, these variations will cause color changes in reflected light. The second contributor is the actual light source. The quality of the light reflecting off of a film can impact the amount of iridescence observed. The more "smooth" the emission spectrum of the light source is, the less iridescence there will be.

The "whiter" the light is, meaning the closer it comes to emitting all colors, the less iridescence will be observed. Some types of bulbs are designed to simulate white light by emitting at only a few specific colors across the spectrum, which uses less energy. Incandescent or halogen bulbs, or full spectrum LED lights have relatively smooth spectra across all visible wavelengths of light. Lower quality LED lights, fluorescent lights, and sodium or mercury bulbs have "peaks" at some wavelengths, which interfere in a very detectable manner since there are no other colors to "cancel out" the effect. This problem appears in higher contrast when it is dark outside, and illuminated indoors.

Emission Spectrum: The colors of the light that a bulb or other source emits



Top to bottom: The emission spectrum of fluorescent, "white" LED, and metal halide light sources

What does this mean for window film?

The bad news for the window film industry and end users is that iridescence cannot be eliminated in existing products. The good news is that lighting solutions can help alleviate the problem.

Iridescence is an issue that affects all window films, and does not stem from the quality of manufacturing used in making the product. An equivalent product in a competitor's portfolio will encounter the same level of iridescence as a Bekaert film, so switching manufacturers will not eliminate this optical issue.

To completely eliminate iridescence, it is necessary to do one or more of three things: maintain an absolutely uniform coating thickness, use materials which all have the same index of refraction, or use lighting that interferes less or not at all. Because thickness variations in the hardcoat would need to be controlled to the micron level (down to millionths of a meter), it is for practical purposes impossible to coat at this uniformity with current technology. Controlling hardcoat thickness is not currently actionable. "Index matching" describes a potential solution by matching the index of refraction of the PET film and hardcoat. This is a potential long term solution, but will not be available in the near future due to the fact it means working with new, more complex chemistry.

The current viable solution to mitigating iridescence is working with alternative lighting. Understanding how sources emit light, and the wavelengths of light they emit, is the key to choosing lighting appropriate to reducing iridescence. As a general rule:

1) Full spectrum "white" light will not cause iridescence. This includes white incandescent bulbs, most halogen lighting, and many LED bulbs, because there are no "spikes" in the spectrum.
2) Many fluorescent bulbs will cause iridescence, due to the fact that they emit most of their light in three or four specific colors.
3) Some fluorescent bulbs will interfere less with some films than others, depending on which wavelengths the fluorescent light emits.

What can I do if a customer encounters iridescence?

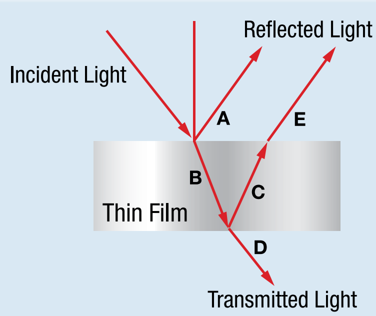
Several actions are possible depending on the circumstances and customer requirements:

- When iridescence is observed or reported, see if adding additional white lighting reduces or eliminates the effect to the satisfaction of the customer.
- Attempt to use a fluorescent light with different emission peaks, or more emission peaks. This requires viewing the manufacturer emission spectra for the bulb.
- Replace the fluorescent lighting with some form of white lighting, such as incandescent, halogen, or high quality LED lights. A good source to collect information on lighting specifications, which often include spectra, is http://www.pegasusassociates.com/
- If options to replace lighting are limited, try replacing bulbs with a warmer color may improve the aesthetic appearance of the film. We recommend bulbs such as daylight by Phillips F32T8-750, or 760, or GE full spectrum bulb 750 or 760.
- If you expect this issue may become a problem, consider adding small portable lamps and a few types of bulbs in an "iridescence test kit" to respond to customer complaints

Interference of Light: A Closer Look

When a light strikes a film, part of the light will be immediately reflected at the surface (A), and part of it will enter the film (B). At the next interface, the light that has entered the film will again be partially reflected (C) and partly transmitted (D). Some of the film that was reflected at the second interface will leave the film and join the initially reflected light (E).

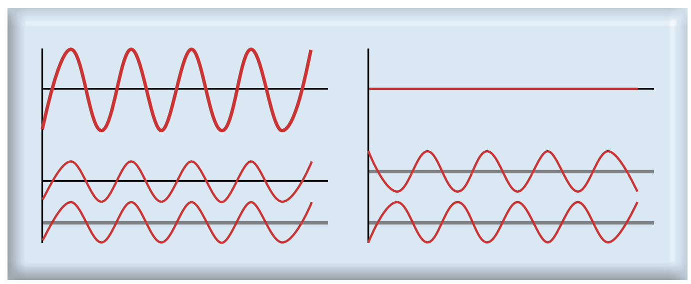
Index of Refraction: A property of a substance related to the speed of light through that substance. For instance, this number for air is 1, water is 1.33, and PET is 1.57. As light passes from one index of refraction to another, it bends.



Light behavior in a thin film

Light entering the film is refracted, and the part of it that is reflected back out from inside the film has traveled a different distance than light reflected at the surface of a film. When the light reflected at the surface (A) meets with the light that returns reflected from the second surface (E), the waves combine. It is this at recombination of light where the light "interferes" with itself.

Light is a wave, and waves that overlap are added together. When reflected light comes off of the film system (pictured above), the rays (A) and (E) will add together. Constructive interference occurs when two positive values add together to create an even higher value. Destructive interference occurs when a "positive" value of one wave cancels out a "negative" value of a second wave, resulting in no value. When applied to light on window films, which have varying film thicknesses, this creates the mottled or striped effect. Specific spots on the surface of the film become brighter (points of maxima) and other locations become dark spots (points of minima) based on the different path length the light inside has traveled.



Constructive interference (left) and destructive interference (right)

When a light source with only a few wavelengths strikes a film, the effect is more pronounced. Interference still occurs when full white light strikes a film, but because each color is refracted at a different angle in the film, there are no "holes" between maxima or minima on a film. A point on the surface of a film that may be a minimum for red, may also be a maximum for orange, and a partially lit by yellow, green, and blue. Full white light fills in the holes left by light that emits only a few colors.

If the coating of a film were uniform, alternating maxima and minima along the surface of a film would not occur. The light reflected off of a uniform film would still appear a different color, but elimination of the variation would eliminate the stripes and "mottled" spots, since all points of the film would be experiencing the same level of interference.

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